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A Remarkable Influence of the Trifluoromethyl Group on the Reactions of β-Mercaptoalcohols with Fluorinated α-Bromoenones

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Abstract: Isomeric fluorinated α-bromoenones react with dinucleophilic β-mercaptoalcohols in CH_2Cl_2 at room temperature in the presence of Et_3N in a multistep process. Depending on the position of the CF_3 group, different *O,S*-heterocycles or non-cyclic products were obtained. Whereas in the case of 3-bromo-1,1,1-trifluorobut-3-en-2-ones derivatives of 1,4-oxathianes were formed, the isomeric 2-bromo-4,4,4-trifluorobut-2-en-1-ones yielded 1,3-oxathiolanes or non-cyclic sulfides. The thia-Michael addition is proposed as the initial step of the reaction, and the final heterocyclization is governed by the location of the CF_3 group.

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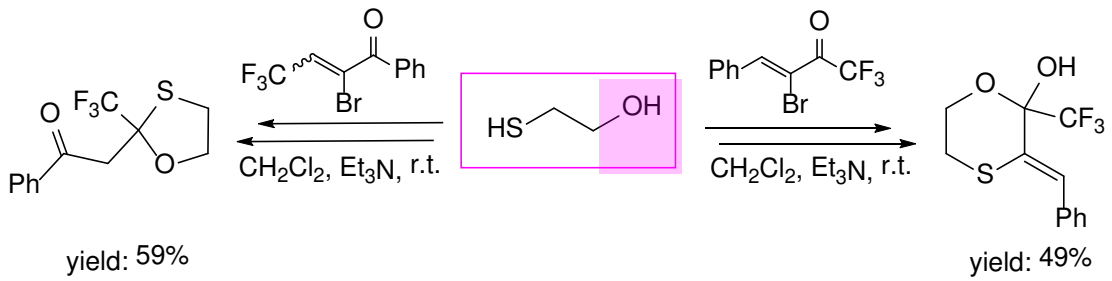
KEYWORDS

Fluorinated enones, mercaptoalcohols, thia-Michael addition, heterocyclization, trifluoromethylated *S*-heterocycles

Graphical abstract:



Graphical abstract-text: β-Mercaptoalcohols react smoothly as binucleophilic agents with fluorinated α-bromoenones, and the type of the formed products depends strongly on the location of the CF_3 group in the enones. Whereas 2-bromo-4,4,4-trifluorobut-2-en-1-ones yield the corresponding 5-membered 1,3-oxathiolanes or, alternatively, open chain sulfides, reactions with isomeric 3-bromo-1,1,1-trifluorobut-3-en-2-ones lead to 6-membered 1,4-oxathiane derivatives, exclusively.

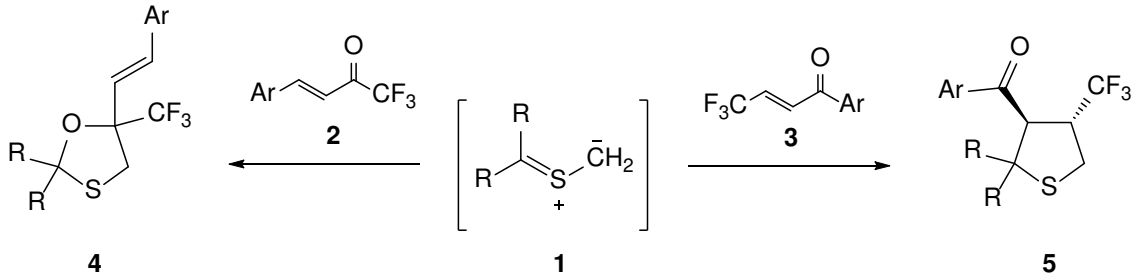
Introduction

Reactions generally known as Michael addition are widely applied for the synthesis of both chiral and achiral organic compounds.[1] Depending on the structure of the Michael acceptor and the nucleophilic Michael donor, the reaction leads to diverse acyclic final products. Michael reactions with dinucleophiles open access to a plethora of heterocycles with diverse ring size and heteroatoms via an addition/heterocyclization sequence.

The development of methods for the synthesis of fluorinated heterocycles is of current interest,[2] and reactions with fluorinated Michael acceptors, especially with α,β-unsaturated trifluoromethylketones, offers a straightforward approach to this class of compounds.[3] In a series of recent publications, reactions of 3-bromo-1,1,1-trifluorobut-3-en-2-ones with dinucleophiles such as 1,2-diamines and β-aminoalcohols have been studied in detail.[4] The formation of piperazine and morpholine derivatives, respectively, was explained via a cascade of reaction steps, initiated by the Michael-type addition. Moreover, in a recent study, α-bromo(trifluoromethyl)enones were described as prone heterodienes, which reacted with α,β-unsaturated aldehydes in the presence of

an organocatalyst to give highly substituted fluoroalkylated 3,4-dihydro-2*H*-pyrans in an asymmetric hetero-Diels-Alder reaction.[5a]

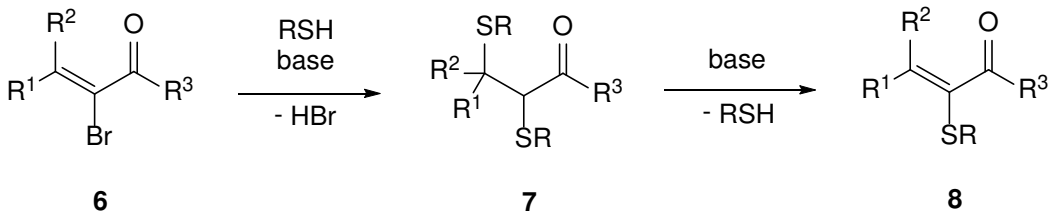
On the other hand, we reported that electron-rich thiocarbonyl *S*-methanides **1** react chemoselectively with isomeric 1,1,1-trifluorobut-3-en-2-ones (**2**) and 4,4,4-trifluorobut-2-en-1-ones (**3**) yielding 1,3-oxathioles **4** or tetrahydrothiophene derivatives **5**, respectively, as products of the [3+2]-cycloaddition (Scheme 1).[5b] Based on this observation, and prompted by results reported by Nenajdenko and collaborators,[4] we decided to examine reactions of β-mercaptoalcohols as binucleophilic agents with α-bromoenones derived from **2** and **3**.



Scheme 1. Chemoselective [3+2]-cycloadditions of the in situ generated thiocarbonyl *S*-methanides **1** with trifluoromethylated α,β-unsaturated ketones **2** and **3**.

Thiols are known as excellent nucleophiles in Michael addition reactions, and thiol-Michael additions have been studied extensively. Two recent comprehensive reviews summarize its importance in materials chemistry[6] and biological chemistry.[7] In the latter case, the thia-Michael addition found application for the detection of thiols in living cells.[8]

The reactions of non fluorinated α-bromoenones **6** with aliphatic and aromatic thiols, performed in the presence of a base, gave either α,β-disulfanyl ketones **7** or α-sulfanylenones **8** resulting from a sequence of addition and elimination reactions[9] (Scheme 2).



6 **7** **8**

Scheme 2. Addition-elimination reactions of α-bromoenones **6** with thiols performed in the presence of a base.

In a very recent publication we reported on reactions of diverse thiols and selenols, including β-mercaptoalcohols, with electron deficient dialkyl dicyanofumarates.[10] In these systems, instead of the expected thia-Michael addition, a new redox reaction, resulting in the formation of the corresponding disulfides or diselenides, respectively, was observed. The course of the reaction was rationalized by a SET mechanism, which replaced the expected addition of the reactive R–XH (X = S or Se) nucleophile to the C=C bond.

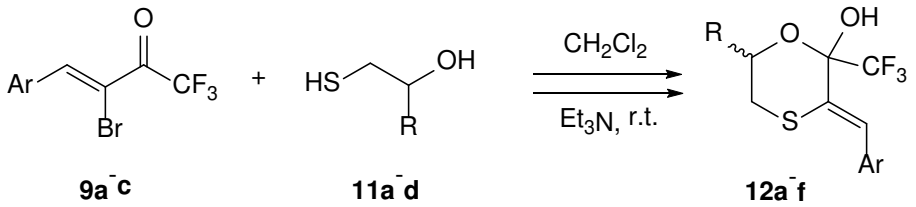
The goal of the present study was to examine whether the reaction of fluorinated α-bromoenones with β-mercaptoalcohols is limited to the Michael addition or heterocyclization within the initially formed adduct will lead to fluorinated *O,S*-heterocycles. In addition, the influence of the position of the CF_3 group on the reaction course and the type of the final products should be investigated.

Results and Discussion

Earlier studies with fluorinated α-bromoenones relate to 4-aryl-3-bromo-1,1,1-trifluorobut-3-en-2-ones **9** exclusively.[4] The isomeric 1-aryl-2-bromo-4,4,4-trifluorobut-2-en-1-ones **10** were prepared for the present study as a mixture of (*E/Z*)-stereoisomers from enones **3**[5b] via a bromination/dehydrobromination procedure. An alternative method for its preparation was a multistep reaction starting with 2-bromo-3,3,3-trifluoropropene leading to (*E*)-configured enones **3**, which subsequently were converted to (*E*)-**10**.

In a test experiment, α-bromoenone **9a** was reacted with mercaptoethanol (**11a**) in CH_2Cl_2 solution in the presence of an excess of Et_3N at r.t. The TLC control showed

that the reaction was complete after 48 h. The chromatographic separation led to a colorless solid. The ^{1}H-NMR spectrum showed four characteristic signals at 4.18, 4.02, 3.20 and 2.86 ppm, corresponding to a CH_2O and a CH_2S group. In the ^{13}C-NMR spectrum, these groups absorbed at 60.1 and 28.7 ppm, respectively. Two quartets found at 122.2 ($^{1}J_{C,F}$ = 285.0 Hz) and 96.7 ppm ($^{2}J_{C,F}$ = 31.5 Hz) were attributed to a CF_3–C unit. Correlation analysis allowed to identify an olefinic unit C=CH by the presence of two signals at 123.0 and 128.3 ppm. The strong IR absorption at 3379 cm^{-1} indicated the presence of an OH group. Finally, the ESI-MS showed a peak at *m/z* 275.2 (100%), which corresponded to $[M+1]^+$ for $C_{12}H_{10}F_3O_2S$. Based on these data, the structure of the obtained compound corresponded to a 1:1-adduct after elimination of HBr and could be formulated as 1,4-oxathiane derivative **12a**, most likely with (*Z*)-configuration of the C=C bond (Scheme 3).



9a–**c** **11a**–**d** **12a**–**f**

a Ar = Ph
b Ar = 4-ClC$_6$H$_4$
c Ar = 4-MeOC$_6$H$_4$

a R = H
b R = Me
c R = PhCH$_2$OCH$_2$
d R = CH$_2$=CHCH$_2$OCH$_2$

a Ar = Ph, R = H (49%)
b Ar = Ph, R = Me (15%; d.r. 96:4)
c Ar = Ph, R = PhCH$_2$OCH$_2$ (38%; d.r. 90:10)
d Ar = Ph, R = CH$_2$=CHCH$_2$OCH$_2$ (27%; d.r. 91:9)
e Ar = 4-ClC$_6$H$_4$, R = H (47%)
f Ar = 4-MeOC$_6$H$_4$, R = H (17%)

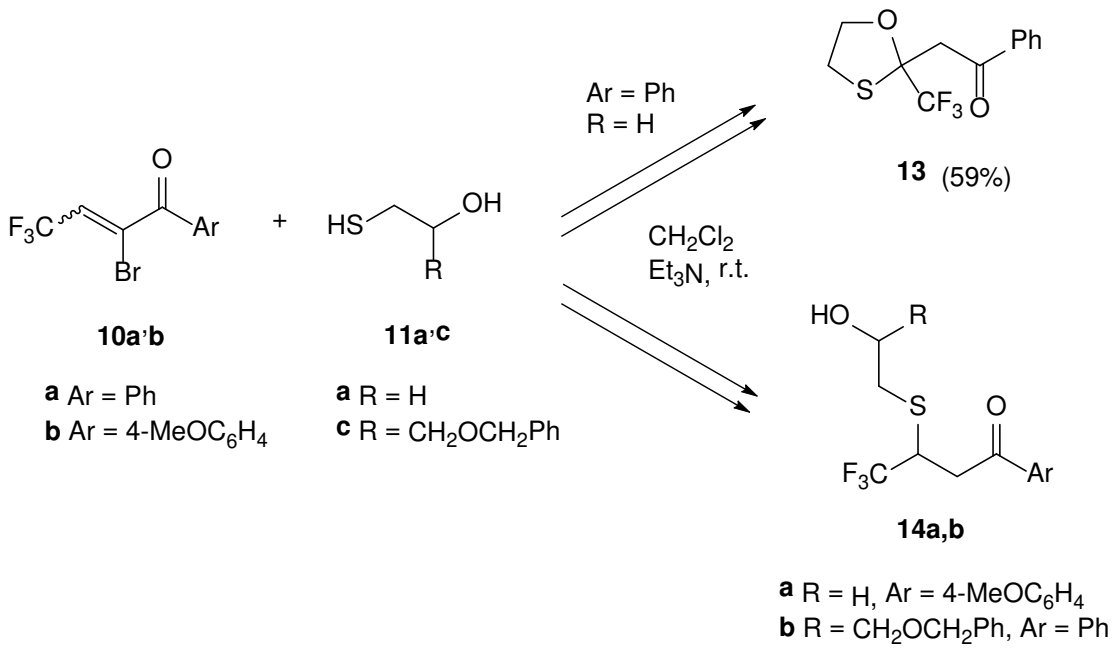
Scheme 3. Reactions of α-bromoenones **9** with β-mercaptoalcohols **11** to give 1,4-oxathiane derivatives **12**.

Using the same reaction conditions, α-bromoenone **9a** was reacted with β-mercaptoalcohols **11b–d**, and in all cases the corresponding 1,4-oxathianes **12b–d** were isolated as sole products in variable yields (49–15%). In all three cases the isolated material consisted of a mixture of two diastereoisomers for which the d.r. values were determined in a range of 96:4 to 90:10 based on the registered ^{19}F NMR spectra. All attempts to separate these mixtures, including semi-preparative flash chromatography, were unsuccessful. In addition, enones **9b**,**c** with a 4-chlorophenyl and 4-methoxyphenyl group, respectively, and **11a** gave the expected products of type **12**. In

the case of **9c**, the yield of the isolated product **12f** was low (17%). The chromatographic separation of the reaction mixture delivered, along with the desired product **12f**, a comparable amount of an oily material, which, according to the registered spectra, consisted of a mixture of non-identified compounds.

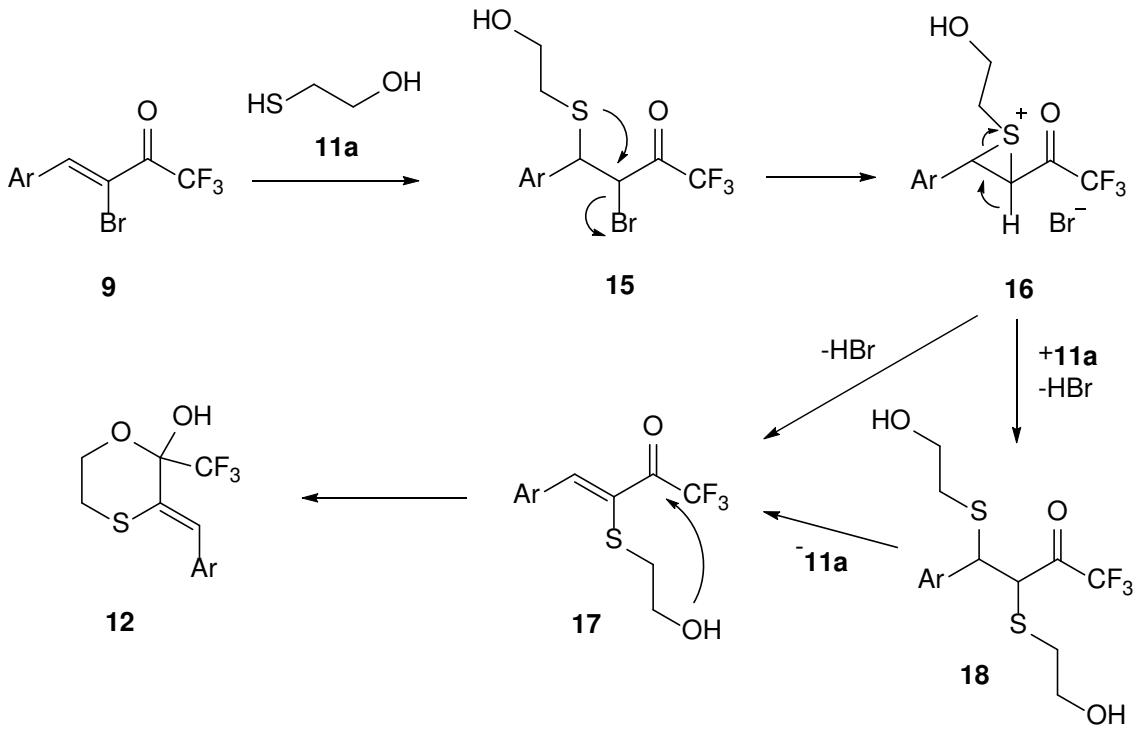
In order to compare the influence of the CF_3 group, mercaptoethanol **11a** was tested in the reaction with α-bromoenone **10a**, which is an isomer of **9a**, under the same conditions (CH_3Cl_2, Et_3N, r.t.). In that case, the product was obtained as an oily material. The ^{1}H NMR spectrum revealed the presence of three CH_2 groups, registered as two multiplets at 4.29–4.19 and 3.15–3.06 ppm and a singlet at 3.65 ppm. In the ^{13}C NMR spectrum, an absorption at 194.1 ppm was attributed to a ketone C=O group, evidenced by a strong absorption at 1698 cm^{-1} in the IR spectrum. Again, two signals at 124.9 ($^1J_{C,F}$ = 289.5 Hz) and 92.0 ppm ($^2J_{C,F}$ = 30.0 Hz) were attributed to a CF_3–C fragment. The ESI-MS showed the [M+1]-peak at *m/z* 277.1 (85%). Also in that case, the structure of the product corresponded with that of the initial 1:1-adduct after elimination of HBr and subsequent heterocyclization. Thus, it can be formulated as the 1,3-oxathiolane derivative **13** (Scheme 4).

When the reaction of **11a** was performed with **10b**, bearing a 4-methoxyphenyl substituent, another reaction course was observed, and the sulfide **14a** was isolated in 76% yield. The structure of this compound was elucidated on the basis of its spectroscopic data. In addition, the same type of sulfide, **14b**, was obtained in 34% yield when **10a** was reacted with **11c**. Also in this case, the isolated product was identified as an inseparable mixture of two diastereoisomers in a ratio ca.1:1 (^{19}F NMR).



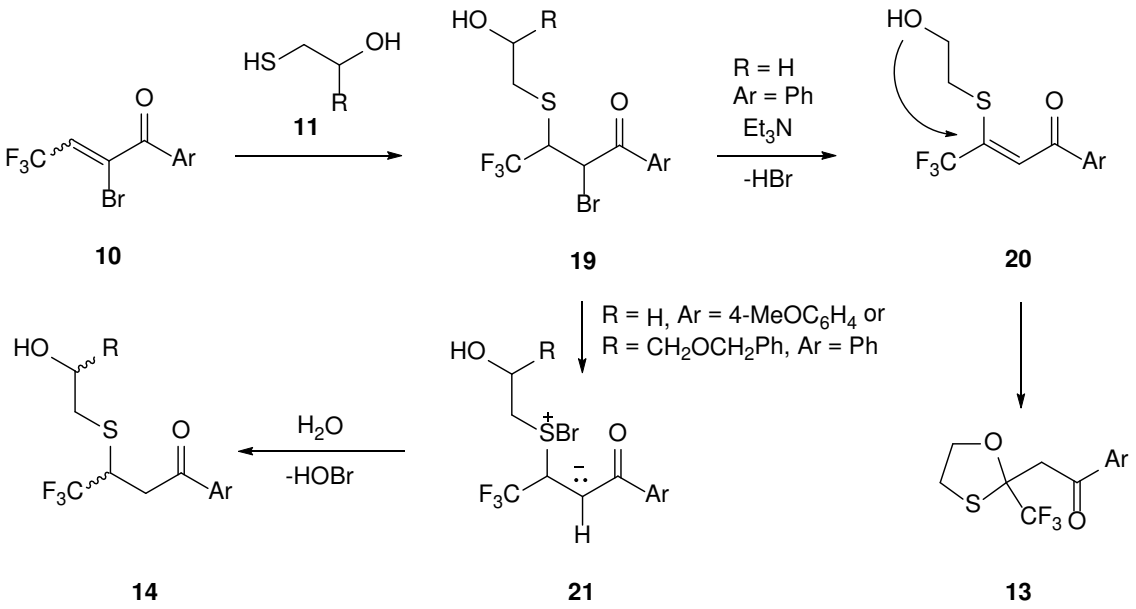
Scheme 4. Reactions of α-bromoenones **10** with β-mercaptoalcohols **11a**,**c**

The obtained results demonstrate that the position of the CF_3 group in the α-bromoenones determines the reaction course and the type of the resulting product. A plausible mechanistic pathway leading to the 1,3-oxathianes **12** is presented in Scheme 5. The initial step of the reaction sequence comprises the thia-Michael addition to give 15, which easily undergoes the intramolecular nucleophilic substitution leading to the thiiranium salt **16**. The latter intermediate undergoes deprotonation and simultaneous thiirane ring opening. The resulting capto-dative olefin **17** forms the heterocyclic product **12** via an intramolecular acetalization. The last step corresponds with the well-known tendency of fluorinated aldehydes and ketones to form stable hydrates and hemiacetals. An alternative formation of **17** can be proposed via addition of **11a** to **16** to give **18**, and subsequent elimination of **11a**. No attempts were made to evidence the appearance of the thiiranium cation **16** but analogous intermediates are frequently postulated in reactions of β-halogen-substituted sulfides or thiols[9] with nucleophiles (so called 'neighbouring group participation'). However, in a recent study, the attempted NMR detection of an intermediate of that type was completely unsuccessful.[11]



Scheme 5. Proposed reaction mechanism for the formation of 1,4-oxathianes **12**.

The explanation of the reaction pathway leading to 1,3-oxathiolane **13** from α-bromoenone **10a** and **11a** via the Michael adduct **19** as key intermediate is based on the assumption that after elimination of HBr the α,β-unsaturated ketone **20** is formed (Scheme 6). The latter undergoes preferably the heterocyclization leading to the 1,3-oxathiolane **13**. On the other hand, the formation of sulfides **14** can be rationalized by intramolecular substitution of the Br atom ($S_Ni(Hal)$)[12] in **19**. This step leads to the zwitterionic intermediate **21**, which reacts with water to give **14**.



Scheme 6. Reaction mechanisms for the formation of 1,3-oxathiolane **13** and sulfides **14**.

Conclusions

The presented study shows that in addition to 1,2-diamines and β-aminoalcohols, β-mercaptoalcohols are useful dinucleophiles for exploration in reactions with fluorinated α-bromoenones as superior Michael acceptors. The comparison of the results obtained with isomeric fluorinated butenones demonstrates that the CF_3 group governs the reaction course. In both systems studied, the initially formed thia-Michael adducts undergo further transformations, and in both reaction pathways, the final heterocyclization occurs via intramolecular nucleophilic attack of the OH group at the electrophilic sp^2-C-atom bearing the activating CF_3 group. In two of the studied cases, the initially formed Michael adducts undergo an intramolecular halogen-substitution, which is a competitive process of the sequence HBr-elimination/cyclization.

The presented results open straightforward ways for the synthesis of very little known fluoroalkylated 1,4-oxathianes and 1,3-oxathiolanes. Diverse compounds derived from both systems have extensively been studied as biologically active compounds [13a-e-new;] and some applications of ligands derived from 1,3-oxathianes in asymmetric synthesis are also reported [13f-new].

Experimental Section

General Remarks: All reactions were carried out in oven-dried glassware under inert atmosphere (N_2), CH_2Cl_2 was dried over CaH_2 and distilled prior to use. Column chromatography purifications were performed with silica gel 60 (230-400 mesh). Thin layer chromatography was carried out on TLC plates (silica gel 60 F254). ^{1}H NMR (600 MHz) and ^{13}C NMR spectra (150 MHz) were recorded in $CDCl_3$ using a Bruker Avance III 600 spectrometer. ^{19}F NMR spectra (188 MHz) were recorded on Varian Gemini 200 spectrometer. NMR signals were referenced to residual non-deuterated solvent signals (7.26 ppm for ^{1}H, 77.0 ppm for ^{13}C). The abbreviations used are: s (singlet), d (doublet), dd (doublet of doublet), m (multiplet), b (broad). IR spectra were measured using a NEXUS FT-IR spectrophotometer (as film or KBr pellets). The ESI-MS spectra were obtained using a Varian 500 MS LS Ion Trap spectrometer. HRMS (ESI) were registered using a GCT Premier Waters instrument.

Starting materials

Commercially available solvents and mercaptoethanol (**11a**) were used. β-Mercaptoalcohols **11b–d** were synthesized according to ref.[13] The fluorinated β-bromoenones of type **9**[14] and **10**[15] were prepared based on the published procedures.

Synthesis of 4-aryl-1,1,1-trifluorobut-3-en-2-ones 2

General procedure: Trifluoroacetone (2.0 g, 17.8 mmol) was added to the solution of an appropriate aromatic aldehyde (4.40 mol), acetic acid (400 mg, 6.67 mmol) and piperidine (300 mg, 3.53 mmol) in anhydrous toluene while cooling the reaction flask in an ice-bath (0° C). The reaction mixture was left over night and was then diluted with CH_2Cl_2 (~10 ml) and a saturated aqueous solution of NH_4Cl. The organic layer was separated and the water phase was washed with CH_2Cl_2 (3x10 ml). The combined organic layers were dried over anhydrous Na_2SO_4, filtrated, and finally the solvents were removed under reduced pressure. The crude products were purified on an automatic flash chromatography system on SiO_2 columns with mixtures of petroleum ether with increasing amounts of CH_2Cl_2 (0–5%) as an eluent.

4-Phenyl-1,1,1-trifluorobut-3-en-2-on (**2a**).[5] Yield: 449 mg (51%); yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.97 (d, $^3J_{H,H}$ = 16.0 Hz, 1H, CH), 7.65–7.64 (m, 2 arom. CH), 7.50–7.44 (m, 3 arom. CH), 7.02 (d, $^3J_{H,H}$ = 16.0 Hz, 1H, CH) ppm.

4-(4-Chlorophenyl)-1,1,1-trifluorobut-3-en-2-on (**2b**).[16] Yield: 485 mg (47%); yellow crystals, m.p. 62.4–63.5 ºC (without crystallization) (lit.[16a], m.p. 43−46 °C). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.92 (d, $^3J_{H,H}$ = 16.0 Hz, 1H, CH), 7.59–7.57 (m, 2 arom. CH), 7.44–7.43 (m, 2 arom. CH), 6.99 (d, $^3J_{H,H}$ = 16.0 Hz, 1H, CH) ppm.

4-(4-Methoxyphenyl)-1,1,1-trifluorobut-3-en-2-on (**2c**).[5] Yield: 314 mg (31%); yellow semi-solid, m.p. 54.3–55.5 ºC. ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.94 (d, $^3J_{H,H}$ = 15.8 Hz, 1H, CH), 7.61–7.60 (m, 2 arom, CH), 6.96–6.95 (m, 2 arom. CH), 6.89 (d, $^3J_{H,H}$ = 15.8 Hz, 1H, CH), 3.87 (s, 3H, CH_3) ppm.

Synthesis of 4-aryl-3-bromo-1,1,1-trifluorobut-3-en-2-ones 9

General procedure: A solution of Br_2 (240 mg, 1.5 mmol) in CH_2Cl_2 (~2 ml) was added dropwise to an enone **2** (1.5 mmol) dissolved in anhydrous CH_2Cl_2 (~10 ml). Next, Et_3N (227 mg, 2.25 mmol) was added, and the reaction mixture was stirred over 12 h. The progress of the reaction was controlled via ^{1}H NMR spectroscopy, and if the elimination of HBr was not complete, an additional portion of Et_3N (227 g, 2.25 mmol) was added. The reaction mixture was left over night, then a portion of H_2O (~20 ml), was added. The organic layer was separated, and the water phase was washed with CH_2Cl_2 (3x10 ml). The combined organic layers were dried over anhydrous Na_2SO_4, filtrated, and the solvent was evaporated under reduced pressure. Pure products were isolated by column chromatography on SiO_2 with petroleum ether with an increasing amount of CH_2Cl_2 (0–25%) as an eluent.

(Z)-3-Bromo-4-phenyl-1,1,1-trifluorobut-3-en-2-on (**9a**).[14b] Yield: 352 mg (84%); yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 8.21 (s, 1H, CH), 7.98–7.96 (m, 2 arom. CH), 7.55–7.49 (m, 3 arom. CH) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 175.9 (q, $^2J_{C,F}$ = 34.5 Hz, C=O), 147.3 (q, $^5J_{C,F}$ = 4.5 Hz, CH), 132.9 (1 arom. C), 132.1, 131.3, 128.8 (5 arom. CH), 115.8 (q, $^1J_{C,F}$ = 289.5 Hz, CF_3), 116.7 (CBr) ppm. ^{19}F NMR (188 MHz,

$CDCl_3$): δ –69.09 (s, CF_3) ppm. IR (film): *v* 1714*vs* (C=O), 1207–1147*s* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z* $[M + H]^+$: 278 (100%), 280 (100%).

(Z)-3-Bromo-4-(4-chlorophenyl)-1,1,1-trifluorobut-3-en-2-on (**9b**).[4c] Yield: 348 mg (74%); yellow crystals, m.p. 83.4–84.2 ºC (without crystallization). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.49–7.47 (m, 2 arom. CH), 7.93–7.90 (m, 2 arom. CH), 8.14 (s, 1H, CH) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 175.8 (q, $^2J_{C,F}$ = 34.5 Hz, C=O), 145.7 (q, $^5J_{C,F}$ = 4.5 Hz, CH), 138.3, 131.2 (2 arom. C), 132.5 129.2 (4 arom. CH), 118.6 (CBr), 115.7 (q, $^1J_{C,F}$ = 289.5 Hz, CF_3) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –69.15 s, CF_3) ppm. IR (KBr): *v* 1704*vs* (C=O), 1204–1157*s* (CF_3) cm^{-1}. ESI-(–)-MS: *m/z* $[M – H]^-$: 312 (70%), 314 (100%).

(Z)-3-Bromo-4-(4-methoxyphenyl)-1,1,1-trifluorobut-3-en-2-on (**9c**).[14b] Yield: 0.394 mg (85%); orange semi-solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 8.14 (s, 1H, CH), 8.05–8.04 (m, 2 arom. CH), 7.01–7.00 (m, 2 arom. CH), 3.90 (s, 3H, CH_3) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 175.7 (q, $^2J_{C,F}$ = 34.5 Hz, C=O) 163.0, 146.9 (2 arom. C), 134.2, 114.4 (4 arom. CH), 125.4 (CH), 117.9 (q, $^1J_{C,F}$ = 289.5 Hz, CF_3), 113.9 (CBr), 55.5 (CH_3O) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –68.72 (s, CF_3) ppm. IR (KBr): *v* 1701*s* (C=O), 1185–1150*s* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z* $[M + H]^+$: 309 (97%), 311 (100%).

Synthesis of 1-aryl-4,4,4-trifluorobut-2-en-1-ones 3

General procedure: 2-Bromo-3,3,3-trifluoropropene (4.7 g, 0.027 mol) was dissolved in anhydrous THF (30 ml) and the reaction flask was cooled to –78 ^{o}C. Next, a solution of LDA, prepared from diisopropylamine (5.4 ml, 0.035 mol) in THF (30 ml) and a 2.5M solution of *n*-BuLi in hexane (14 ml, 0.035 mol) at –78 ^{o}C, was added dropwise and the mixture was stirred over 15 min. Then, an appropriate aromatic aldehyde (0.015 mol), dissolved in THF (~5 ml), was added. The cooling bath was removed and the reaction flask was left to reach room temperature. Next, a 1M solution of HCl (50 ml) and AcOEt (50 ml) were added. The organic layer was separated and the water layer was washed with AcOEt (3x50 ml). The combined organic layer was dried over anhydrous Na_2SO_4, filtrated, and the solvents were removed under reduced pressure. The crude 1-aryl-4,4,4-trifluorobut-2-yn-1-oles were used for next step without purification.

A 1-aryl-4,4,4-trifluorobut-2-yn-1-ol was dissolved in THF (120 ml) and Et_3N (6.06 g, 0.060 mol) was added. The reaction mixture was heated to 60 °C over 12 h in an Ar atmosphere. Next, the solvent was removed in rotary evaporator. The products were purified by column chromatography on SiO_2 with petroleum ether with increasing amounts of CH_2Cl_2 (9:1) as the eluent. The diastereoisomers (*E/Z*) were not separated.

1-Phenyl-4,4,4-trifluorobut-2-en-1-on (**3a**).[15b] Yield (for 2 steps): 1.59 g (53%); yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ *E*-isomer: 7.98 (d, $^3J_{H,H}$ = 7.1 Hz, 1H, CH), 6.82 (dq, $^3J_{H,F}$ = 13.3 Hz, $^3J_{H,H}$ = 7.1 Hz, 1H, CH); *Z*-isomer: 7.93 (d, $^3J_{H,H}$ = 7.6 Hz, 1H, CH), 6.09 (dq, $^3J_{H,F}$ = 15.8 Hz, $^3J_{H,H}$ = 7.6 Hz, 1H, CH); both diastereoisomers 7.66–7.64 (m, 2 arom. CH), 7.55–7.52 (m, 3 arom. CH) ppm.

1-(4-Methoxyphenyl)-4,4,4-trifluorobut-2-en-1-on (**3b**).[15b] Yield (for 2 steps): 1.41 g (41%); yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ *E*-isomer: 7.99–7.96 (m, 2 arom. CH), 7.53 (dq, $^4J_{H,F}$ = 2.0 Hz, $^3J_{H,H}$ = 14.4 Hz, 1H, CH), 7.01–6.89 (m, 2 arom. CH), 6.79 (dq, $^3J_{H,F}$ = 6.7 Hz, $^3J_{H,H}$ = 14.4 Hz, 1H, CH), 3.90 (s, 3H, CH_3O); *Z*-isomer: 7.91–7.89 (m, 2 arom. CH), 6.98–6.96 (m, 2 arom. CH), 6.82 (d, $^3J_{H,H}$ = 12.8 Hz, 1H, CH), 6.04 (dq, $^3J_{H,F}$ = 7.9 Hz, $^3J_{H,H}$ = 12.8 Hz, 1H, CH), 3.89 (s, 3H, CH_3O) ppm.

Syntheses of 1-aryl-2-bromo-4,4,4-trifluorobut-2-en-1-ones 10

General procedure: A solution of Br_2 (930 mg, 5.8 mmol) in dry n-hexane (~2 ml) was added dropwise to the solution of a fluoroenone **3** (5.8 mmol) in dry n-hexane (30 ml). The solution was stirred until disappearance of the red color. Next, a portion of water (50 ml) was added, and the mixture was extracted with Et_2O (3x25 ml). The organic layers were combined and dried over anhydrous Na_2SO_4, filtered, and the solvents were removed under reduced pressure. The crude dibromoderivative was dissolved in Et_2O (30 ml), Et_3N (0.81 g, 8.0 mmol) was added, and the solution was stirred for 24 h. The precipitated triethylammonium bromide was filtrated off and the solvent was removed under reduced pressure. The product was purified by column chromatography on SiO_2 with petroleum ether with increased amounts of CH_2Cl_2 (0–25%) as the eluent.

2-Bromo-1-phenyl-4,4,4-trifluorobut-2-en-1-on (**10a**).[17] Yield: 1.15 g (72%) (single diastereoisomer); yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.87–7.86 (m, 2 arom.

CH), 7.67–7.65 (m, 1 arom. CH), 7.54–7.51 (m, 2 arom. CH), 6.76 (q, $^3J_{H,F}$ = 6.8 Hz, 1H, CH) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 188.7 (C=O), 134.4, 130.3, 128.9 (5 arom. CH), 133.4 (1 arom. C), 130.4 (CBr), 126.9 (q, $^2J_{C,F}$ = 36.6 Hz, $CHCF_3$), 121.4 (q, $^1J_{C,F}$ = 267.4 Hz, CF_3) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –69.93 (d, $^3J_{F,H}$ = 7.2 Hz, CF_3) ppm. IR (film): *v* 1685*s* (C=O), 1242–1150*s* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z* $[M + H]^+$: 279 (100%), 281 (92%).

2-Bromo-1-(4-methoxyphenyl)-4,4,4-trifluorobut-2-en-1-on (**10b**). Yield: 1.31 g (73%) (both diastereoisomers, ratio 7:3); yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ major isomer: 7.89–7.87 (m, 2 arom. CH), 6.67 (q, $^3J_{H,F}$ = 6.8 Hz, 1H, CH); minor isomer: 7.92–7.90 (m, 2 arom. CH), 6.64 (q, $^3J_{H,F}$ = 7.3 Hz, 1H, CH); both isomers 7.00–6.98 (m, 2 arom. CH), 3.91 (s, 3H, CH_3O)ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ major isomer: 187.3 (C=O), 164.8, 125.8 (2 arom. C), 132.4, 114.3 (4 arom. CH), 130.1 (q, $^3J_{C,F}$ = 6.0 Hz, CBr), 125.3 (q, $^2J_{C,F}$ = 36.0 Hz, $CHCF_3$), 121.5 (q, $^1J_{C,F}$ = 271.5 Hz, CF_3), 55.7 (CH_3O); minor isomer: 186.5 (C=O), 165.0, 125.2 (2 arom. C), 132.3, 114.4 (4 arom. CH), 129.7 (q, $^3J_{C,F}$ = 6.0 Hz, CBr), 122.4 (q, $^2J_{C,F}$ = 36.0 Hz, $CHCF_3$), 121.1 (q, $^1J_{C,F}$ = 271.5 Hz, CF_3), 55.6 (CH_3O) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ major isomer –65.86 (d, $^3J_{F,H}$ = 5.6 Hz, CF_3), minor isomer –61.70 (d, $^3J_{F,H}$ = 5.6 Hz, CF_3) ppm. IR (film): *v* 1682*s* (C=O), 1312–1138*vs* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z* $[M + H]^+$: 309 (100%), 311 (97%).

Synthesis of β-mercaptoalcohols 11c,d

1-(Benzyloxy)-3-mercaptopropan-2-ol (**11c**)

Obtained following the reported procedure.[13] Yield: 562 mg (89%); yellowish oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.38–7.31 (m, 5H), 4.56 (brs, 2H, CH_2Ph), 3.88–3.82 (m, 1H, CHOH), 3.57 (dd, *J* = 4.5, 9.6 Hz, 1H, $CH_a\mathbf{H_b}O$), 3.53 (dd, *J* = 6.1, 9.6 Hz, 1H, $C\mathbf{H_a}H_bO$), 2.75–2.62 (m, 2H, CH_2S), 1.44 (t, *J* = 8.7 Hz, 1H, SH) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 137.9, 128.4, 127.9, 127.4, 73.3, 72.2, 71.2, 28.1 (CH_2S) ppm. EI-MS: *m/z*: 198 (37) $[M^{+\cdot}]$, 122 (45), 107 (73), 91 (100). $C_{10}H_{14}O_2S$ (198.28): calcd. C 60.58, H 7.12; found: C 60.51, H 7.17.

1-(Allyloxy)-3-mercaptopropan-2-ol (**11d**)

Obtained following reported procedure.[13] Yield: 527 mg (71%); yellowish oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.95–5.85 (m, 1H), 5.30–5.19 (m, 2H), 4.04–4.02 (m, 2H, C**H$_2$**OCH=CH_2), 3.87–3.81 (m, 1H, CHOH), 3.53 (dd, *J* = 4.3, 9.5 Hz, 1H, CH_a**H$_b$**O), 3.49 (dd, *J* = 6.2, 9.5 Hz, 1H, C**H$_a$**H_bO), 2.74–2.61 (m, 2H, CH_2S), 2.39 (brs, 1H, OH), 1.48 (t, *J* = 8.7 Hz, 1H, SH) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 134.7, 117.6, 72.6, 71.1, 70.6, 28.4 (CH_2S) ppm. ESI-(+)-MS: *m/z* $[M+Na]^+$: 171 (100). $C_6H_{12}O_2S$ (148.22): calcd. C 48.62, H 8.16; found: C 48.50, H 8.21.

Reactions of bromoenones 9 and 10 with β-mercaptoalcohols

General procedure: A β-mercaptoalcohol **11a–d** (1 mmol) and Et_3N (0.152 g, 1.5 mmol) were added to a solution of an *α*-bromoenone **9a–c** or **10a**,**b** (1 mmol) in anhydrous CH_2Cl_2 (10 ml). The solution was stirred in an Ar atmosphere for 48 h. Then, the solvent was removed under reduced pressure and the product was purified by column chromatography on SiO_2 with petroleum ether with increased amounts of CH_2Cl_2 (0–100%) as an eluent.

3-Benzylidene-2-(trifluoromethyl)-1,4-oxathian-2-ol (**12a**). Yield: 136 mg (49%); colorless crystals, m.p. 135.8–137.4 ºC (hexane/CH_2Cl_2). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.56–7.54 (m, 2 arom. CH), 7.41–7.39 (m, 2 arom. CH), 7.34–7.31 (m, 2H, 1 arom. CH + CH=C), 4.20–4.17 (m, 1H, CH_2), 4.04–4.00 (m, 1H, CH_2), 3.26–3.22 (m, 1H, CH_2), 3.15 (s, 1H, OH), 2.87–2.84 (m, 1H, CH_2) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 135.4 (**C**H=C), 134.9 (1 arom. C), 129.9, 128.3, 128.1 (5 arom. CH), 123.0 (CH=**C**), 122.2 (q, $^1J_{C,F}$ = 285.0 Hz, CF_3), 96.7 (q, $^2J_{C,F}$ = 31.5 Hz, **C**CF_3), 60.1 (CH_2O), 28.7 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –84.00 (s, CF_3) ppm. IR (KBr): *ν* 3379*br.s* (OH), 1188–1141*vs* (CF_3) cm^{-1}. ESI-(–)-MS: *m/z*: 275 (25%, $[M - H]^-$), 276 (100%, $[M]^-$). HR-ESI-(–)-MS: 275.0352 (275.0354 calcd. for $C_{12}H_{10}F_3O_2S$, $[M - H]^-$).

3-Benzylidene-6-methyl-2-(trifluoromethyl)-1,4-oxathian-2-ol (**12b**). Yield: 43 mg (15%); yellow oil (two diastereoisomers, ratio 96:4). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.54–7.53 (m, 2 arom. CH), 7.40–7.39 (m, 2 arom. CH), 7.33–7.30 (m, 2H, 1 arom. CH + CH=C), 4.19–4.14 (m, 1H, C**H**CH_3), 3.10 (s, 1H, OH), 2.95 (dd, $^2J_{H,H}$ = $^3J_{H,H}$ = 11.2 Hz, 1H, CH_2S), 2.83 (dd, $^2J_{H,H}$ = 11.2 Hz, $^3J_{H,H}$ = 6.4 Hz, 1H, CH_2S), 1.36 (d, $^3J_{H,H}$ = 6.2 Hz , 3H, CH_3) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 135.1 (1 arom. C), 134.7 (**C**H=C), 129.9, 128.2, 128.1 (5 arom. CH), 123.2 (CH=**C**), 122.1 (q, $^1J_{C,F}$ = 286.1 Hz,

CF_3), 96.9 (q, $^2J_{C,F}$ = 31.7 Hz, **C**CF_3), 67.0 (**C**HCH_3), 34.6 (CH_3), 21.0 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ major isomer –84.45 (s, CF_3); minor isomer –80.32 (s, CF_3) ppm. IR (film): *v* 3443*br.s* (OH), 1188–1097*vs* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z* 273 (100%, $[M–OH]^+$). HR-ESI-(–)-MS: 289.0506 (289.0510 calcd. for $C_{13}H_{12}F_3O_2S$, $[M – H]^–$).

3-Benzylidene-6-(benzyloxymethyl)-2-(trifluoromethyl)-1,4-oxathian-2-ol (**12c**). Yield: 149 mg (38%); yellow oil (two diastereoisomers, ratio 90:10). ^1H NMR (600 MHz, $CDCl_3$): δ 7.55–7.54 (m, 2 arom. CH), 7.40–7.29 (m, 9H, 8 arom. CH + CH=C), 4.58 (s, 1H, OH), 4.59–4.54 (m, 2H, **C**H_2Ph), 4.25–4.23 (m, 1H, C**H**CH_2OBn), 3.66 (dd, $^2J_{H,H}$ = 10.5 Hz, $^3J_{H,H}$ = 6.1 Hz, 1H, CHC**H**$_2$OBn), 3.53 (dd, $^2J_{H,H}$ = 10.5 Hz, $^3J_{H,H}$ = 4.6 Hz, 1H, CHC**H**$_2$O), 3.01 (dd, $^2J_{H,H}$ = $^3J_{H,H}$ = 11.3 Hz, 1H, CH_2S), 2.89 (dd, $^2J_{H,H}$ = 11.3 Hz, $^3J_{H,H}$ = 2.9 Hz, 1H, CH_2S) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 137.7 (**C**H=C) , 135.3, 135.0 (2 arom. C), 129.9, 128.5, 128.3, 128.0, 127.9, 127.7 (10 arom. CH), 123.3 (CH=**C**), 122.1 (q, $^1J_{C,F}$ = 285.0 Hz, CF_3), 97.0 (q, $^2J_{C,F}$ = 31.6 Hz, **C**CF_3), 73.5, 71.5, 69.6 ($2CH_2$ + CH), 30.6 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ major isomer –83.55 (s, CF_3); minor isomer –80.47 (s, CF_3) ppm. IR (film): *v* 3357*br.s* (OH), 1198–1112*vs* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z* 419.1 (100%, $[M + Na]^+$), 435 (49%, $[M + K]^+$). HR-ESI-(+)-MS: 419.0898 (419.0905 calcd. for $C_{20}H_{19}F_3O_3SNa$, $[M + Na]^+$).

6-(Allyloxymethyl)-3-benzylidene-2-(trifluoromethyl)-1,4-oxathian-2-ol (**12d**). Yield*:* 92 mg (27%); yellow oil (two diastereoisomers, ratio 91:9). ^1H NMR (600 MHz, $CDCl_3$): δ 7.55–7.53 (m, 2 arom. CH), 7.41–7.38 (m, 2 arom. CH), 7.33–7.32 (m, 2H, 1 arom. CH + CH=C), 5.92–585 (m, 1H, C**H**=CH_2), 5.30–5.27 (m, 1H, CH=C**H**$_2$); 5.22–5.20 (m, 1H, CH=C**H**$_2$), 4.21–4.17 (m, 1H, C**H**CH_2O), 4.05–4.04 (m, 2H, OC**H**$_2$CH=CH_2), 3.64 (dd, $^2J_{H,H}$ = 10.6 Hz, $^3J_{H,H}$ = 6.2 Hz, 1H, CHC**H**$_2$O), 3.10 (dd, $^2J_{H,H}$ = 10.6 Hz, $^3J_{H,H}$ = 4.6 Hz, 1H, CHC**H**$_2$O), 3.49 (s, 1H, OH), 3.00 (dd, $^2J_{H,H}$ = $^3J_{H,H}$ = 11.2 Hz, 1H, CH_2S), 2.89 (dd, $^2J_{H,H}$ = 11.2 Hz, $^3J_{H,H}$ = 3.0 Hz, 1H, CH_2S) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 135.4, 135.0 (2**C**H=C), 134.3 (1 arom. C), 129.9, 128.3, 128.1 (5 arom. CH), 123.3 (CH=**C**-S), 120.1 (q, $^1J_{C,F}$ = 285.0 Hz, CF_3), 117.5 (CH=**C**H_2), 97.0 (q, $^2J_{C,F}$ = 31.9 Hz, **C**CF_3), 72.5, 71.5, 69.6 ($2CH_2$ + CH), 30.6 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ major isomer –83.57 (s, CF_3); minor isomer –80.46 (s, CF_3) ppm. IR (film): *v* 3341*br.s* (OH), 1198–1100*vs* (CF_3) cm^{-1}. ESI-(–)-MS: *m/z*: 345.3 (100%, $[M – H]^–$);

346 (97%, $[M]^-$). HR-ESI-(+)-MS: 369.0737 (369.0748 calcd. for $C_{16}H_{17}F_3O_3SNa$, $[M+Na]^+$)

3-(4-Chlorobenzylidene)-2-(trifluoromethyl)-1,4-oxathian-2-ol (**12e**). Yield: 146 mg (47%); colorless crystals, m.p. = 143.1–145.8 °C (hexane/CH_2Cl_2). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.50–7.48 (m, 2 arom. CH), 7.37–7.35 (m, 2 arom. CH), 7.27 (s, 1H, CH), 4.21–4.18 (m, 1H, CH_2), 4.03–3.98 (m, 1H, CH_2), 3.27–3.23 (m, 1H, CH_2), 3.15 (s, 1H, OH), 2.88–2.85 (m, 1H, CH_2) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 134.1, 134.0 (**C**H=C + 1 arom. C), 133.4 (1 arom. C), 131.1, 128.3 (4 arom. CH), 123.8 (CH=**C**), 122.1 (q, $^1J_{C,F}$ = 286.2 Hz, CF_3), 96.6 (q, $^2J_{C,F}$ = 31.8 Hz, **C**CF_3), 60.1 (CH_2O), 28.7 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –84.06 (s, CF_3) ppm. IR (KBr): *ν* 3405*br.s* (OH), 1192–1144*vs* (CF_3) cm^{-1}. ESI-(–)-MS: *m/z* 309 (100%, $[M - H]^-$), 310 (80%, $[M]^-$). HR-ESI-(–)-MS: 308.9961 (308.9964 calcd. for $C_{12}H_9F_3O_2SCl$, $[M - H]^-$).

3-(4-Methoxybenzylidene)-2-(trifluoromethyl)-1,4-oxathian-2-ol (**12f**). Yield: 52 mg (17%); colorless crystals, m.p. 102.7–104.2 °C (hexane/CH_2Cl_2). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.54–7.52 (m, 2 arom. CH), 7.27 (s, 1H, CH), 6.93–6.92 (m, 2 arom. CH), 4.19–4.16 (m, 1H, CH_2), 4.03–3.99 (m, 1H, CH_2), 3.84 (s, 3H, CH_3O), 3.24–3.22 (m, 1H, CH_2), 3.11 (br.s, 1H, OH), 2.87–2.85 (m, 1H, CH_2) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 159.6 (1 arom. C), 135.1 (**C**H=C), 131.5, 113.5 (4 arom. CH), 127.7 (1 arom. C), 122.2 (q, $^1J_{C,F}$ = 286.5 Hz, CF_3), 120.4 (CH=**C**), 96.8 (q, $^2J_{C,F}$ = 31.5 Hz, **C**CF_3), 60.0 (CH_2O), 55.3 (CH_3O), 28.7 (CH_2S). ^{19}F NMR (188 MHz, $CDCl_3$): δ –84.02 (s, CF_3) ppm. IR (KBr): *ν* 3383*br.s* (OH), 1195–1144*vs* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z*: 307.1 (100%, $[M + H]^+$). HR-ESI-(–)-MS: 305.0454 (305.0459 calcd. for $C_{13}H_{12}F_3O_3S$, $[M - H]^-$).

1-Phenyl-2-[(2-trifluoromethyl)-1,3-oxathiolan-2-yl]ethan-1-on (**13**). Yield: 164 mg (59%); yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.96–7.95 (m, 2 arom. CH), 7.60–7.57 (m, 1 arom. CH), 7.49–7.46 (m, 2 arom. CH), 4.29–4.19 (m, 2H, CH_2O), 3.66, 3.63 (AB, $^2J_{H,H}$ = 16.3 Hz, 2H, CH_2), 3.15–3.06 (m, 2H, CH_2S) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 194.1 (C=O), 137.3 (1 arom. C), 133.4, 128.6 (5 arom CH), 124.9 (q, $^1J_{C,F}$ = 283.5 Hz, CF_3), 92.0 (q, $^2J_{C,F}$ = 30.0 Hz, **C**CF_3), 73.9 (CH_2O), 42.2 (CH_2), 33.8 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –79.77 (s, CF_3) ppm. IR (film): *ν* 1698*s* (C=O),

1220–1119*s* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z* 277 (85%, $[M + H]^+$). HR-ESI-(–)-MS:: 308.9961 (308.9964 calcd. for $C_{12}H_9F_3O_2SCl$, $[M – H]^–$).

3-[(2-Hydroxyethyl)sulfanyl)]-1-(4-methoxyphenyl)-4,4,4-trifluorobutan-1-on (**14a**). Yield: 233 mg (76%); orange oil. ^1H NMR (600 MHz, $CDCl_3$): δ 7.97–7.94 (m, 2 arom. CH), 6.97–6.95 (m, 2 arom. CH), 4.08–4.04 (m, 1H, CHS), 4.00–3.95 (m, 1H, CH_2O), 3.89 (s, 3H, CH_3O), 3.88–3.83 (m, 1H, CH_2O), 3.91–3.30 (m, 3H, CH_2 + OH), 3.06–3.02 (m, 1H, CH_2S), 2.82–2.77 (m, 1H, CH_2S) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ 193.9 (C=O), 164.3, 129.1 (2 arom. C), 127.2 (q, $^1J_{C,F}$ = 276.2 Hz, CF_3), 130.7, 114.0 (4 arom. CH), 61.3 (CH_2O), 55.6 (CH_3O), 41.8 (q, $^2J_{C,F}$ = 29.6 Hz, **C**HCF_3), 37.5 (CH_2), 36.5 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –72.28 (d, $^3J_{F,H}$ = 8.3 Hz, CF_3) ppm. IR (film): *v* 3458*br.s* (OH), 1676*v*s (C=O), 1263–1174*vs* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z*: 309 (100%, $[M + H]^+$). HR-ESI-(+)-MS: 331.0583 (331.0592 calcd. for $C_{13}H_{15}F_3O_3SNa$, $[M + Na]^+$).

3-[(3-Benzyloxy-2-hydroxypropyl)sulfanyl]-1-phenyl-4,4,4-trifluorobutan-1-on (**14b**). Yield: 135 mg (34%) (two diastereoisomers, ratio 1:1); orange oil. ^1H NMR (600 MHz, $CDCl_3$): δ 7.97–7.88 (m, arom. CH), 7.64–7.61 (m, arom. CH), 7.52–7.49 (m), 7.37–7.33 (m, arom. CH), 7.31–7.28 (m, arom. CH), 4.60–4.55 (m), 4.18–4.12 (m), 4.09–4.02 (m), 3.62–3.55 (m), 3.45–3.38 (m), 3.22 (d, *J* = 6.0 Hz), 3.07 (dd, $J_{(1)}$ = 13.8 Hz, $J_{(2)}$ = 4.2 Hz), 2.90 (d, *J* = 6.6 Hz), 2.83 (dd, $J_{(1)}$ = 13.8 Hz, $J_{(2)}$ = 6.6 Hz) ppm (a complex set of signals, it was impossible to attribute them to particular diastereoisomer). ^{13}C NMR (150 MHz, $CDCl_3$): δ 195.3, 195.2 (C=O), 138.0, 137.9, 136.1, 136.0 (2 arom. C), 134.0, 133.9, 128.8, 128.4, 128.3, 128.2, 127.8, 127.75, 127.7 (10 arom. CH), 127.2, 127.1 (2q, $^1J_{C,F}$ = 276.0 Hz, CF_3), 73.5, 72.7, 72.3, 71.2, 68.7 (HOCH, CH_2O, CH_2Ph), 43.1, 42.3 (q, $^2J_{C,F}$ = 28.5 Hz, **C**HCF_3), 38.2, 38.0 (CH_2), 37.2, 37.0 (CH_2S) ppm. ^{19}F NMR (188 MHz, $CDCl_3$): δ –71.39 and –71.16 (2d, ratio 1:1, $^3J_{F,H}$ = 8.3 Hz for both doublets, CF_3 for two diastereoisomers) ppm. IR (film): *v* 3455*br.s* (OH), 1692*v*s (C=O), 1252–1154*vs* (CF_3) cm^{-1}. ESI-(+)-MS: *m/z*: 421 (100%, $[M + Na]^+$). HR-ESI-(+)-MS: 421.1049 (421.1061 calcd. for $C_{20}H_{21}F_3O_3SNa$, $[M + Na]^+$).

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